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Power harvesting from wind energy

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ABSTRACT

Wind Energy is a major source of non-conventional energy resources. The conversion process of mechanical energy of wind flow into electric energy is a growing field for experiment, research and investment. In this paper the conversion methods of wind flow into electric energy and the various methods of generation, control, optimizations and there gradual evolutions, current status of development are being described with historical chronology. The main problems of wind energy conversion are, obtaining a steady, controlled energy as well as its total dependence on wind flow. The current author group devised and tested a small scale wind energy conversion system in order to resolve part of the problems. The experiment and result of that study are also being discussed.

Key Words: Wind Energy, Wind Turbine, Doubly Fed Induction generator, Wind Energy Conversion

1. INTRODUCTION

Wind power has been harnessed as a source of power around the world for a long time. Wind is air in motion, caused by the uneven heating of the Earth by the Sun. Wind occurs when warm air rises, and cooler air moves in to fill the space. It is estimated that 2% of the solar energy reaching the earth is converted into wind energy. Air is constantly being interchanged between the warm tropics and the cold polar caps. The rotation of the Earth also produces wind. The sun radiates the most heat over the equator and therefore the air there is warmer. Air from both hemispheres is constantly moving toward the equator. The rotation of the Earth causes the cool winds to be deflected from east to west. As the surface of the earth heats and cools unevenly, pressure zones are created that make air move from high pressure to low pressure areas. Wind has been used for centuries to propel ships and the wind routes were well known and used by explorers such as Magellan and Columbus. Wind power was used as a source of mechanical energy on land for thousands of years. The Babylonians constructed windmills for irrigation as early as 1700 BC and Europeans were using windmills by 1000 AD. The amount of energy that can be captured from the wind is exponentially proportional to the speed of the wind. If a windmill were perfectly efficient, the power generated is approximately equal to

$$P = {}^{1}/_{2}\, DAV^3$$

Therefore, if wind speed is doubled, the power in the wind increases by a factor of eight. In reality, because wind turbines are not perfectly efficient, changes in wind velocity do not have such a dramatic effect on wind power, and only 10-30% of the power of the wind can be converted into usable electricity. There are a large number of rotor and turbine design based on whether the turbine will be upwind (rotor facing the wind) or downwind (rotor on the side), the number, size and shape of blades, the load (forces acting on the rotor) and other rotor aerodynamic considerations. Among them as a general phenomenon larger windmill rotors and higher wind speed produce more power. When the wind blows there is a pocket of low pressure formed on the downwind side of the blade. The blade is pulled toward the low pressure making the rotor turn. This is called *lift*. The lift force is stronger than the force, known as *drag*, acting on the front side of the blade. The combination of lift and drag causes the rotor to spin like a propeller, and the turning shaft spins a generator to make electricity. In wind turbine design, the objective is to have a high lift-to-drag ratio. This is accomplished by twisting the blades. The blades are

Wind Power:
Wind power is the conversion of the kinetic energy of wind into useable mechanical energy.

Wind Turbine:
A wind turbine is a device that converts kinetic energy from the wind into useable mechanical or electrical energy.

Renewable Energy Source

Renewable energy is energy which comes from sources which are constantly replenishing like Sun, Wind flow, Water flow, geothermal Heat etc. The efficiency and opportunity of a renewable energy source varies with geographical location. Unlike the fossil fuels most of renewable energies are non-polluting and have a very low damage on eco-system and also much safer than Nuclear Energy. With constant depletion of fossil fuel reserve, Renewable energies are only safe solution for the energy need of our world.

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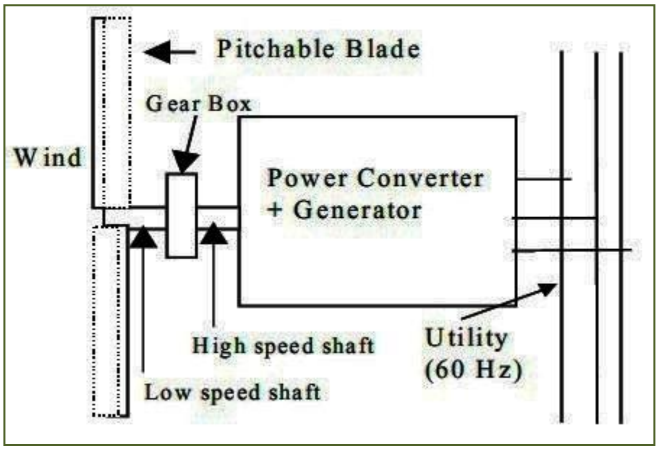

Figure 1
Physical diagram of the system developed by E. Muljadi and C.P. Butterfield

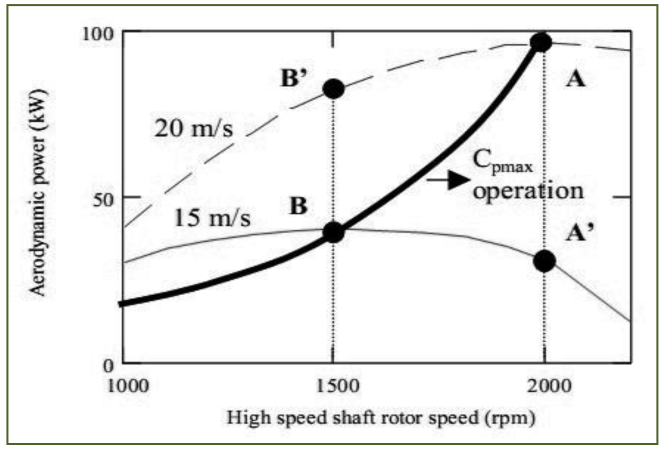

Figure 2
Aerodynamic power versus rpm for two different wind speeds

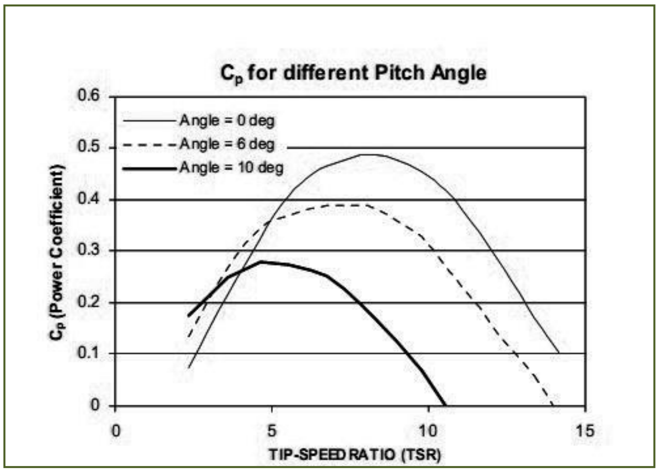

Figure 3
Power coefficient vs. Tip seed ratio for different pitch angle

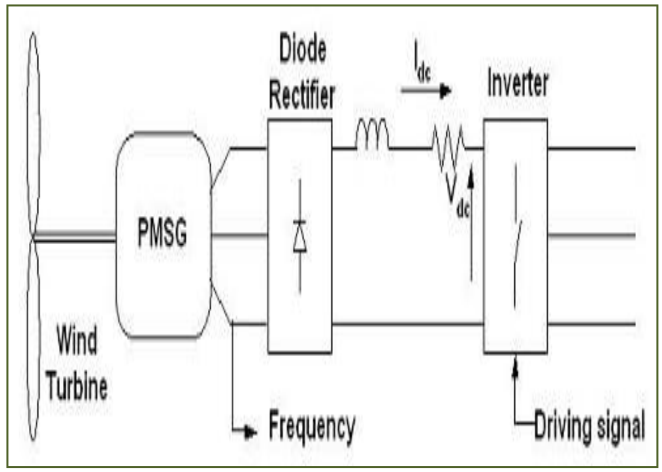

Figure 4
Physical diagram of the system developed by Tan and Islam

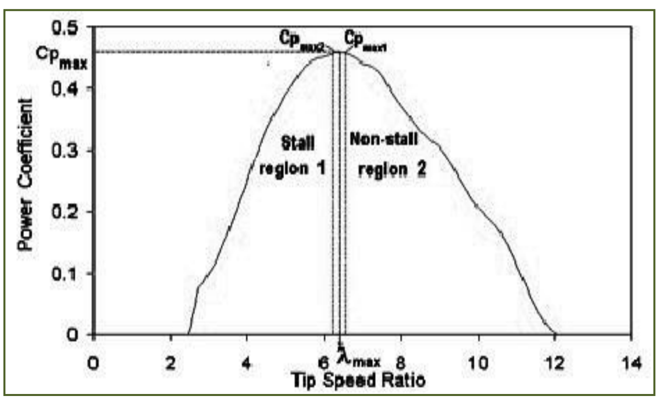

Figure 5
Power coefficient vs. Tip seed ratio

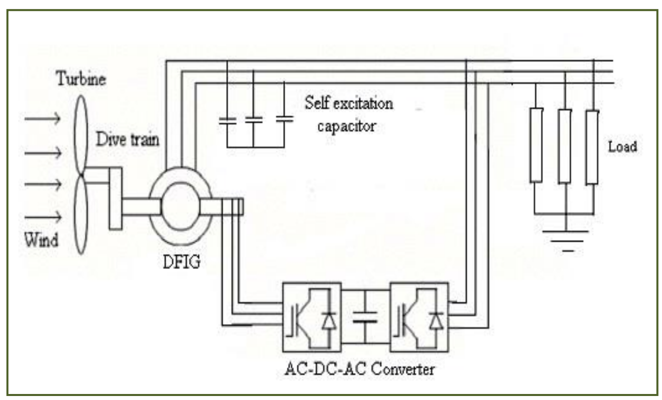

Figure 6
Block Schematic of Wind Turbine Driven Self-Excited DFIGP by P. S. Mayurappriyan

twisted so that the wind hits them at correct angle of attack. This twist is known as *pitch* and the angle in which the blade is twisted is called pitch angle. While wind turbine gives us a considerable amount of clean energy and operates on a low running cost, it has a number of problems, whose solution is a prime goal of many researchers. The huge size of a turbine requires a good initial costing. Also the total set up depends completely on the speed of wind which unlike hydro-power may changes rapidly within a moment's notice. Hence, it is essential to place those towers in places which have heavy flow of wind throughout the year like sea beach etc.

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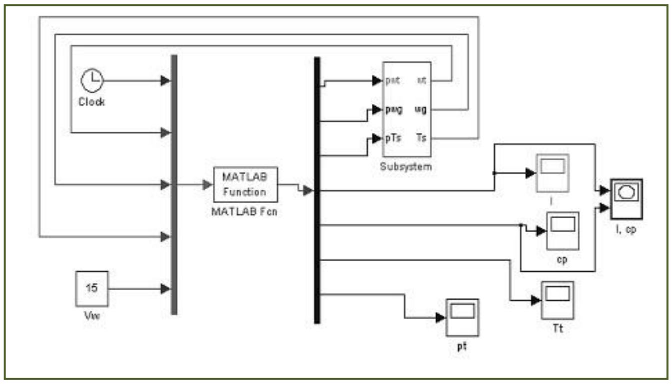

Figure 7

Matlab model of wind turbine P. S. Mayurappriyan

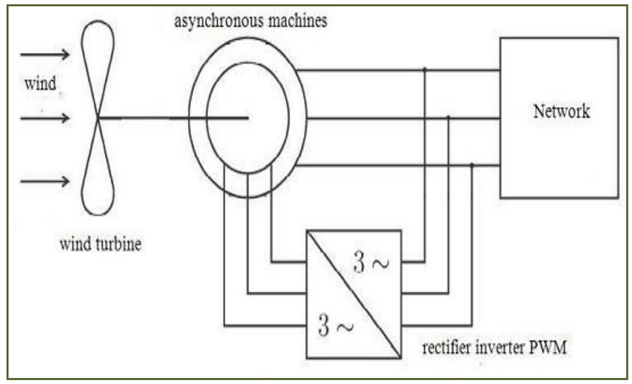

Figure 8

Doubly fed induction generator with converters by A.Naamane

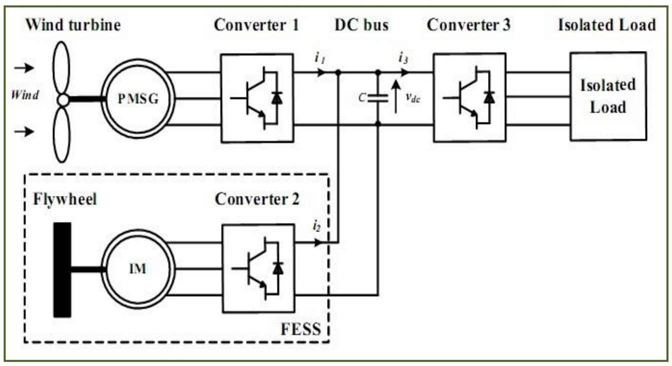

Figure 9

Configuration of the system designed by Mohamed Mansour and his team

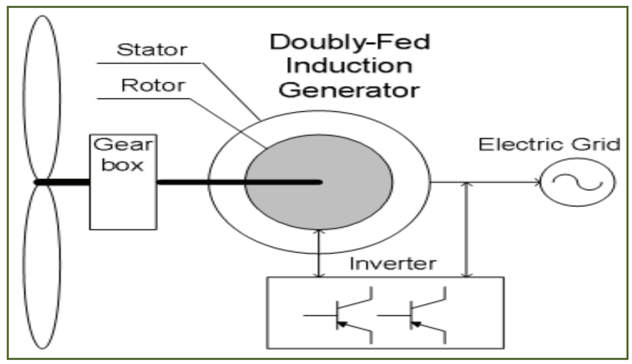

Figure 10

Schematic diagram of a type-3 wind turbine generator

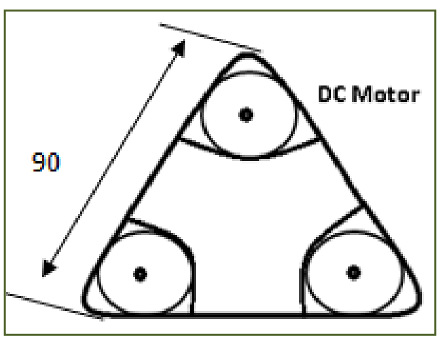

Figure 11

Basic diagram of the turbine

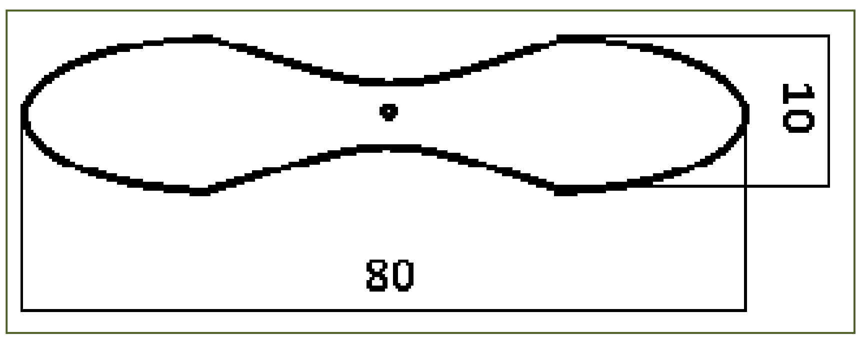

Figure 12

Blade diagram and dimension

2. REVIEW

In the last decade many researches worked on the wind turbine to solve the above mentioned problems. Researches were also conducted on the rotor and the generator of the wind turbine. On February 2000 Muljadi and Butterfield proposed an operation of variable-speed wind turbines with pitch control (Figure 1). The system was controlled to generate maximum energy while minimizing loads. They showed that, by pitch control and generator load control the wind turbine can be operated at its optimum energy capture while minimizing the load and thus extending the range for wind speed (Muljadi, 2000). They simulated a pitch-controlled, variable-speed turbine and tested those two control strategy on it, in different scenarios like high wind speed, low and medium wind speed, limited pitch rate etc (Figures 2, 3) and also implemented the control strategy. During the tests the researchers choose different controlling parameters and generate results based on them. The operative characteristic of the wind turbine and the control strategies were stated. Next year i.e. on 2001 Slootweg et al., published a paper where they discussed on a wind turbine concept where the rotor speed , pitch angle all can be controlled using a doubly fed induction generator. They developed a dynamic model of turbine (Slootweg, 2001) using the doubly fed induction generator and simulated it with respect to fixed wind flow in laboratory.

Nichita et al (2002) proposed two modeling techniques for wind speed simulation. These techniques could be used on the structure of a wind turbine simulator during studies regarding simple or hybrid wind flow. They separated the horizontal wind flow into two; medium speed and long speed components (Nichita, 2002). Then using power spectrum analysis the researchers described several types of wind forms as a combination of these two components like the turbulent wind. Two simulation methods for these components were developed. In both techniques the wind flow is described by two parameters.

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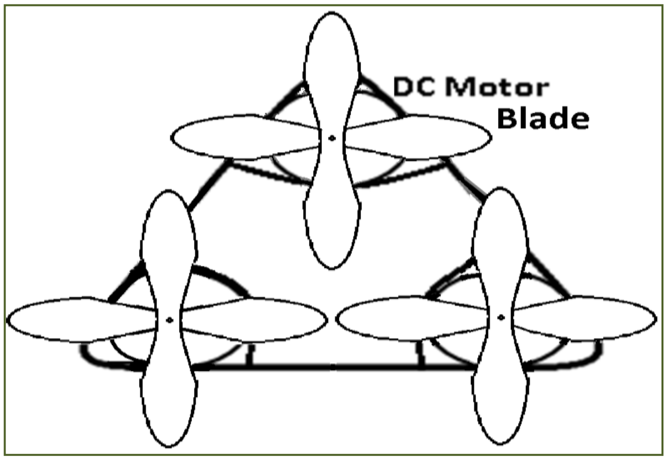

Figure 13
Final Structure of Wind turbine

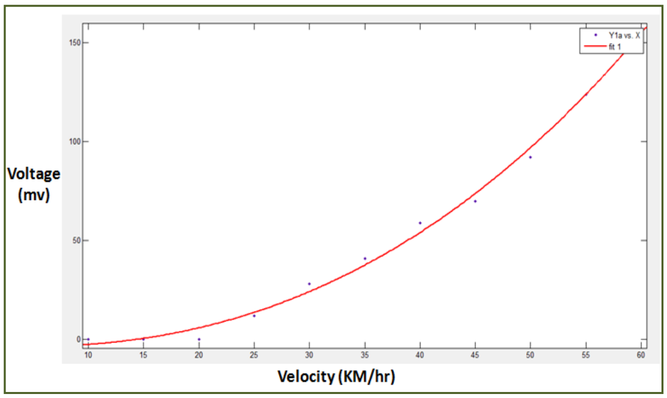

Figure 14
Voltage Generated Vs Wind Speed

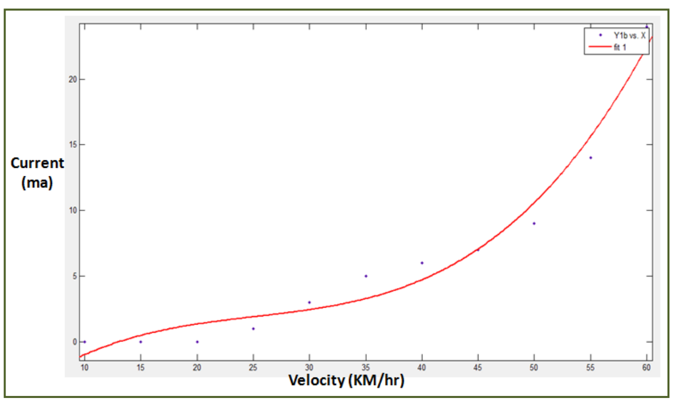

Figure 15
Current Generated Vs Wind Speed

These techniques were then correlated with numerical data obtained by experiments or prepared based on the data obtained at particular sites. Researches were also conducted on optimization and control strategy of wind turbine. In 2004 Tan and Islam performed an experiment showing that the power gained from a wind turbine was not only depends on the character of wind and structure of the system but also on the control strategy used on it. They developed several model of wind energy conversion systems or WECS using software simulation (Figure 4) and use those simulations to evaluate the performance of the existing control strategies (Figure 5). They also proposed a prototype version of the control strategy of a 20-kW permanent-magnet synchronous generator (PMSG) for maximum power tracking and compares with the results produced by previous strategies and demonstrate its advantage over the existing ones (Tan, 2004). The advantages of the proposed model over the existing strategies were elucidated.

In 2006 Yazhou Lei et al discussed on variable speed wind turbine using a doubly fed induction generator to increase the efficiency of the turbine (Lei, 2006). On contrary to the traditional complex models they developed a simple model where the power converter regulates the rotor current as a voltage source. The model thus became simpler than the previous ones without compromising with the performance. As the model was designed in the form of a simple generator the researchers simulated and tested it in software model and discussed on the model's capacity, limitation and possibilities. Next year, on 2007 Demiray and his team studied on the behavior of the double feed induction generator using the *dynamic phasor* approach. They tested the generator as a software simulation under balanced and unbalanced condition and came to conclusion that dynamic approach provides much more accurate model than a static one hence suitable for better control (Demiray, 2007). On 2009 Mayurappriyan and others develop a dynamic model of DFIG (Figure 6) using software simulation (Figure 7) which works without any external trigger signal and uses the power generated by the turbine itself and the test showed, although the model was taking 15-20% of the power generated but it enhance the capability of the system and hence can increase the overall output to make up for the absorbed one (Mayurappriyan, 2009). Same year Jesús López conducted an experiment to reduce the damage of turbine grids caused by voltage dips. They improvised the standard practice of using a crowbar to short-circuit the grid in case of voltage dip and able to reduce the crowbar activation time (López, 2009). As the wind turbine remains without any control when the crowbar activates and thus cause loss of power and a chance to suffer damage by excess voltage generation, López's research reduced that loss to a significant degree.

While double feed induction generators in a wind turbine system was increasing the power output and also reducing the cost, yet there were problems in case of power fault. Since it is required that the turbines must remain connected to grid in case of disturbance and also contribute to voltage support during and after grid disturbance, the generators were prone to get damaged. In order to resolve this Mauricio B. C. Salles proposed a crowbar system to avoid the disconnection the DFIG during a fault in 2010. They also performed a rotor speed analysis to analyze the stability or instability of the DFIG during a grid fault condition (Sales, 2010). In the same year on November A. Naamane and N. K. Msirdi tested different wind turbine control strategies using a DFIG based on direct and indirect control approaches (Naamane, 2010). They modeled and simulated a DFIG based turbine (Figure 8). In their test they analyze the robustness and stability of the generator while changing between different control-strategies. In the year 2011, Mohamed Mansour and his team modeled a *permanent magnet synchronous generator* wind turbine system (Figure 9) and tested it using simulation. They not only designed the generator but also the other required components of it like the filter, inverter, rectifier and bus (Monsour, 2011). They tested and analyzed it and recorded the results and correlated them with various other parameters.

While Doubly Fed Induction Generator provided a sharp rise in power generation, traditional DFIGs could not regulate their active power to support the system frequency due to the operation of maximum power point tracking. They were needed to be down-regulated either by increasing rotor speed or adjusting pitch angle and to be adjusted with required current frequency. However both pitch control and rotor speed control depends heavily on practical scenario and might not be sufficient. Hence to utilize the full capacity of a DFIG Zhang Zhaosui and his team designed a frequency control strategy (Zhang, 2011) to match wind speed and pitch controls. Depending on the wind speeds, the coordination strategy is composed of low, medium and high wind speed control modes and thus adjusts the output into required frequency. In 2012 Ian A. Hiskens studied and analyzed the dynamic behaviors of the type-3 wind turbine generator model (Figure 10). He studied and discussed some conventional control strategies as well as some hybrid strategies. His paper consists of detail discussion (Hiskens, 2012) of the dynamic behavior of the generator including deadlock, hysteresis, equilibrium, steady state characteristics and steady state variables etc.

Wind turbine is a clean energy generator without any harm for mankind; however the main problem of it is the uncertainty and total dependence on wind flow hence the tower is needed to be built in a place with heavy and regular wind flow. Also in

Doubly Fed Induction generator:
Doubly fed electric generators are electric generators that have windings on both stationary and rotating parts, where both windings transfer significant power between shaft and electrical system.

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Table 1
Equations of the Cubic Polynomial Curve obtained from the voltage and current generated in the wind turbine by MATLAB cf tool along with Goodness of curve fitting parameters

Linear model Poly3==> f(x) = p1*x^3 + p2*x^2 + p3*x + p4				
Parameter	Coefficients (with 95% confidence bounds)			
	p1	p2	p3	p4
Voltage	0.00027	0.03324	-0.3427	-2.727
Current	0.0004	-0.0302	0.8559	-6.909
Parameter	Goodness of fit			
	SSE	R^2	adjusted R^2	RMSE
Voltage	139.5	0.9951	0.993	4.464
Current	16.3	0.9699	0.957	1.523

order to gain enough power from a turbine it is needed to be large. The large size of wind turbine adversely affects the avian life forms and poses a threat to the ecological system. This gives a new direction of research which deals with reducing the size of the turbine without hampering the voltage production. The current author group conducted a study on wind turbines. A system is developed with a set of small scale wind turbines (Figures 11, 12, 13) which then fitted to a locomotive that enables the turbines to get exposed to a much higher wind flow. This system is tested in vehicle running in with a varying speed from 10 km/hr to 60 km/hr where it generates a voltage of 157-180 mV and current of 24 mA. It is also tested with a domestic table fan and regulated mouth blow. The said device, as evaluated in various conditions is found to produce controlled electric power (Sengupta, 2012). Curves and equations are generated from the experimental data (Figures 14, 15; Table 1) which correlated well with the predicted value. This small scale turbine may be used in prospective consideration after appropriate instrumentation and miniaturization. However, further works are needed before that.

3. CONCLUSION

The main problem of the wind energy is its complete dependence on the wind flow of nature which unlike most of other energy sources vividly unpredictable in most of the area in the earth. Although worldwide wind currents are being mapped and monitored, the uncertainty and irregularity in wind current is very high. Apart from some places like sea costs, wind current in most of the lands are unsuitable for constant large scale electricity production. Also since only an 8-10% of the total amount of wind power can be converted to electricity, in order to obtain substantial energy the wind mills are needed to be large in size which creates problem in ecosystem and are also criticized for atheistic reasons. In the perspective of society and science wind energy can be one of the major sources of energy in today's world if it can be made dependable. In this paper we reviewed some of the frontline researches going on in this direction. While experiments were and are being conducted on the control strategy, structure design, generator model etc. the idea to use the wind turbine as a small scale energy generator is being nurtured as well, requiring appropriate standardization.

SUMMARY OF RESEARCH

1. This review provides a summary on researches performed on power harvesting from vibration.

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